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(12) **United States Patent**
Sasagawa et al.

(10) **Patent No.: US 9,067,414 B2**
(45) **Date of Patent: Jun. 30, 2015**

(54) **LIQUID EJECTION HEAD AND METHOD OF DRIVING THE SAME**

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(73) Assignee: **Canon Kabushiki Kaisha**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 230 days.

(21) Appl. No.: **13/436,204**

(22) Filed: **Mar. 30, 2012**

(65) **Prior Publication Data**

US 2012/0268511 A1 Oct. 25, 2012

(30) **Foreign Application Priority Data**

Apr. 19, 2011 (JP) 2011-093013

(51) **Int. Cl.**

B41J 29/38	(2006.01)
B41J 2/015	(2006.01)
B41J 2/165	(2006.01)
B41J 2/14	(2006.01)
B41J 2/045	(2006.01)

(52) **U.S. Cl.**

CPC ***B41J 2/14233*** (2013.01); ***B41J 2/04533*** (2013.01); ***B41J 2/04581*** (2013.01); ***B41J 2/04588*** (2013.01); ***B41J 2/04596*** (2013.01); *B41J 2202/11* (2013.01)

(58) **Field of Classification Search**

USPC 347/10–11, 20, 27, 19

See application file for complete search history.

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Primary Examiner — Jason Uhlenhake

(74) *Attorney, Agent, or Firm* — Canon USA, Inc., IP Division

(57) **ABSTRACT**

A liquid ejection head includes a plurality of ejection orifices, liquid chambers, piezoelectric actuators, and driving units, and a control unit. Each ejection orifice ejects liquid, each liquid chamber communicates individually with an ejection orifice, each piezoelectric actuator is disposed individually for a liquid chamber and generates energy to eject liquid, and each driving unit individually drives a piezoelectric actuator. The control unit controls each driving unit to output a first voltage pulse to eject liquid or a second voltage pulse to vibrate a meniscus of liquid in a state in which the meniscus is held in a liquid chamber. The control unit selects ejection orifices used to eject liquid and controls to output the first voltage pulse to them, and selects ejection orifices not used to eject liquid and controls to output the second voltage pulse to them to perform respective concurrent recording and recovery operations.

12 Claims, 19 Drawing Sheets

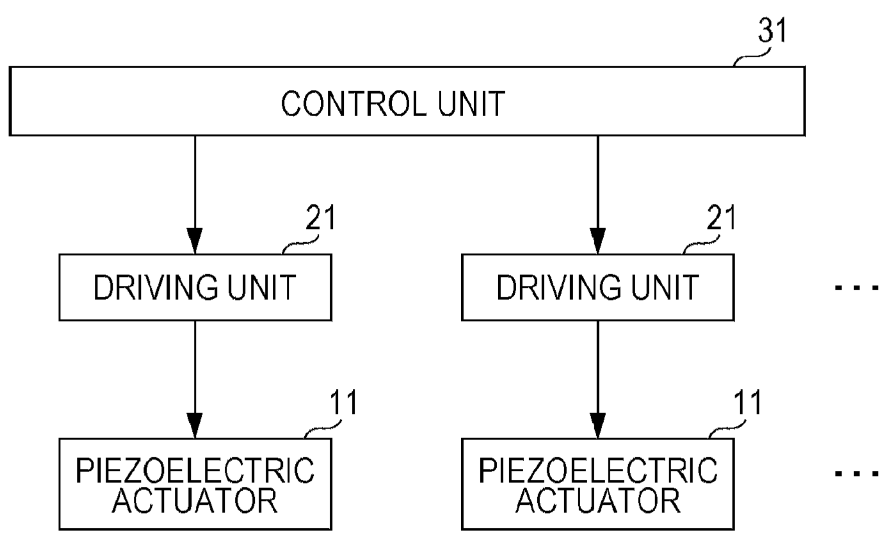


FIG. 1

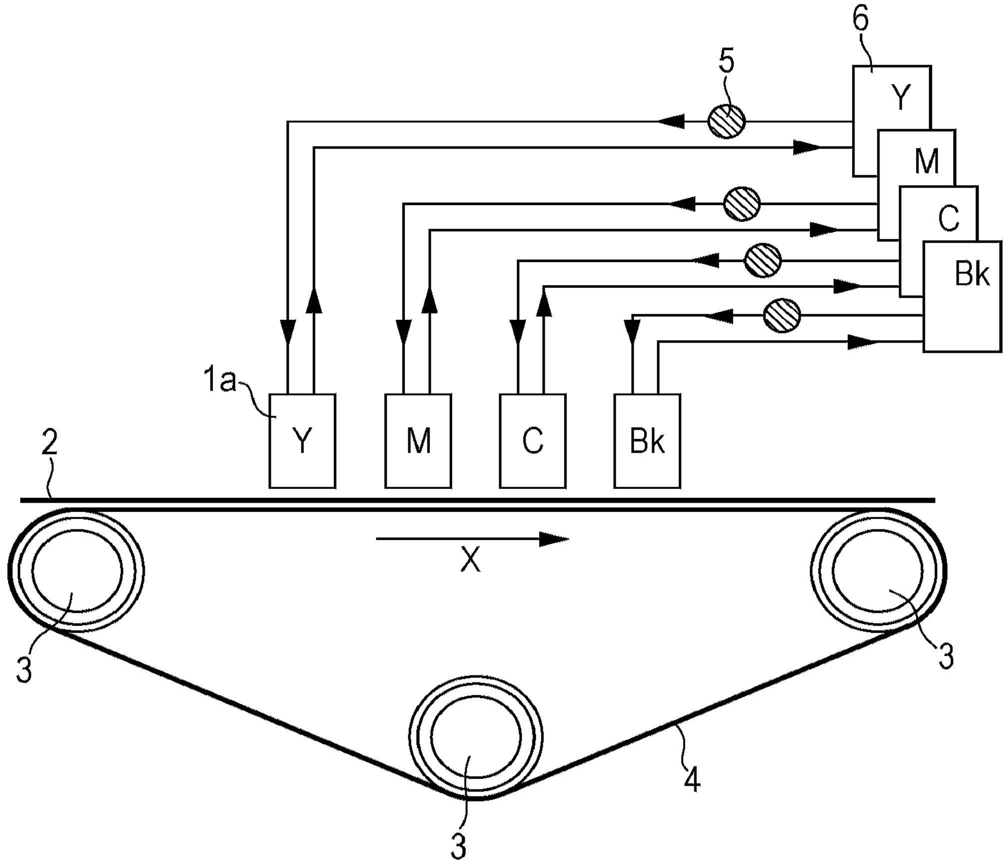


FIG. 2A

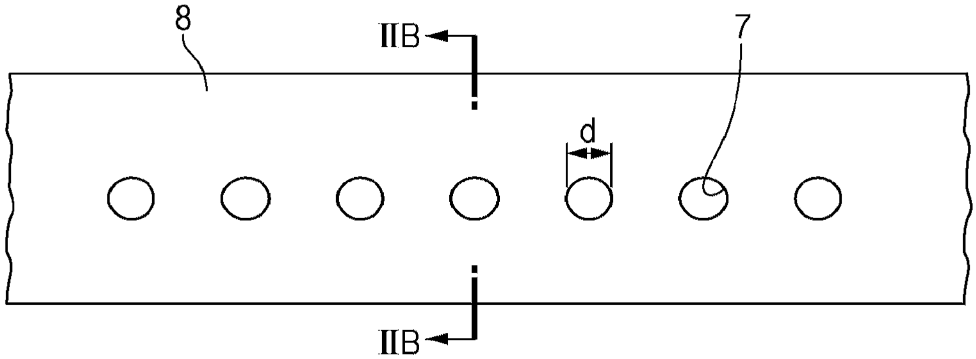


FIG. 2B

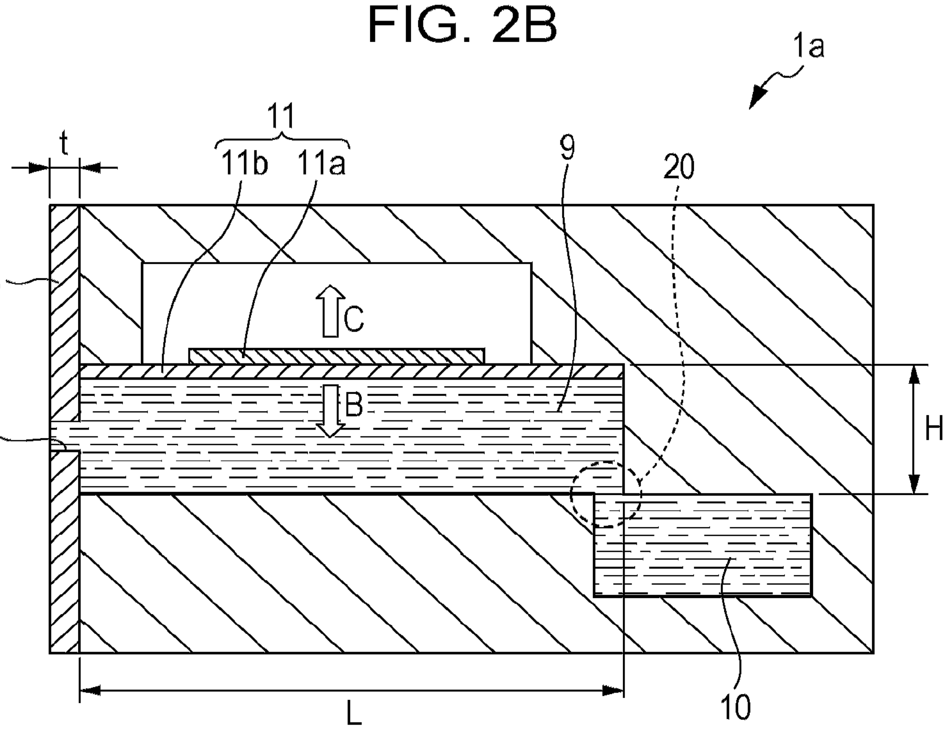
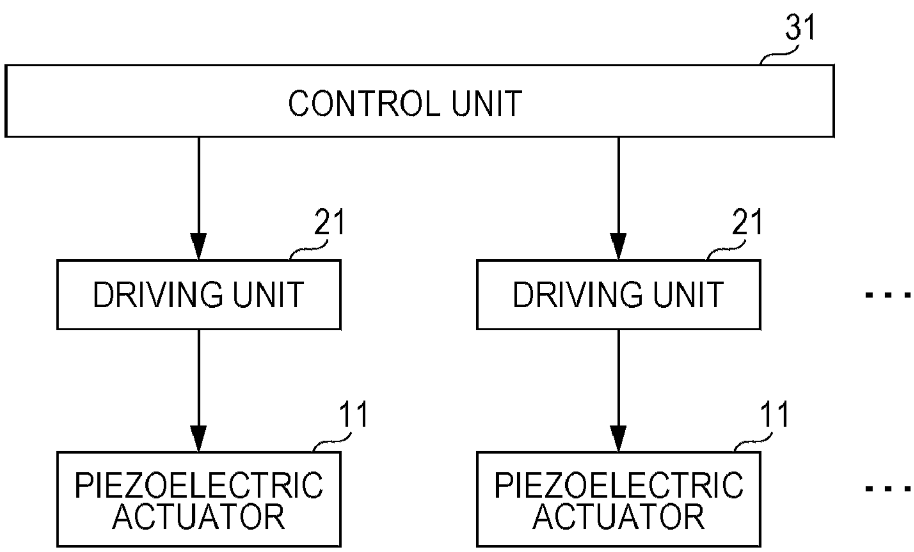


FIG. 3



31
CONTROL UNIT
21
DRIVING UNIT
21
DRIVING UNIT
11
PIEZOELECTRIC ACTUATOR
11
PIEZOELECTRIC ACTUATOR

FIG. 4

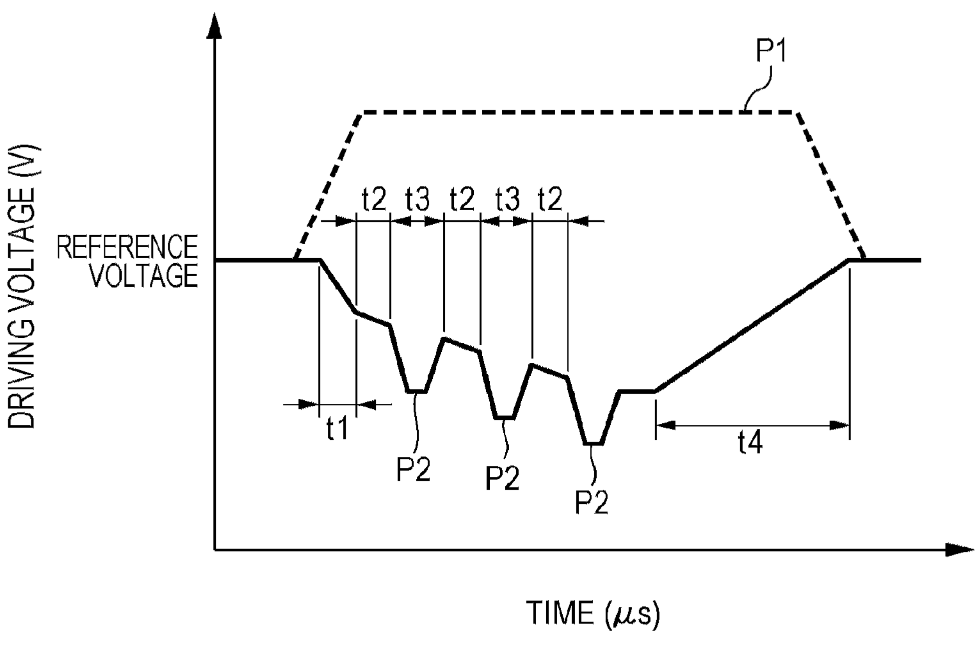

P1
t2
t3
t2
t3
t2
REFERENCE
VOLTAGE
DRIVING VOLTAGE (V)
t1
P2
P2
P2
t4
TIME (μs)

FIG. 5A

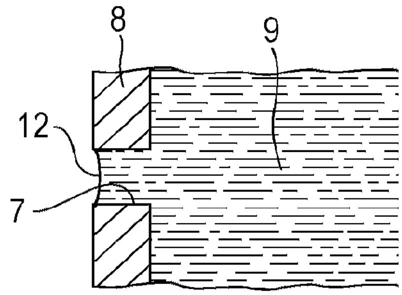


FIG. 5D

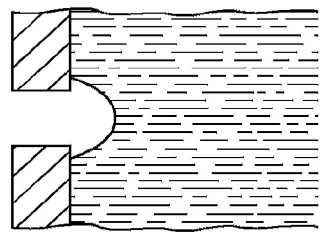


FIG. 5B

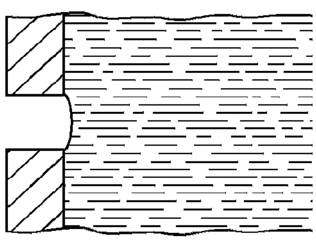


FIG. 5E

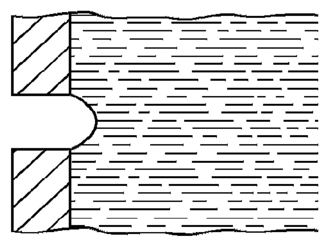


FIG. 5C

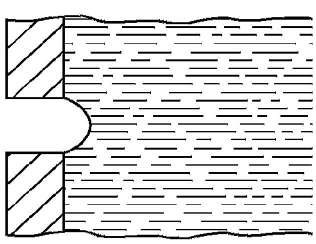


FIG. 5F

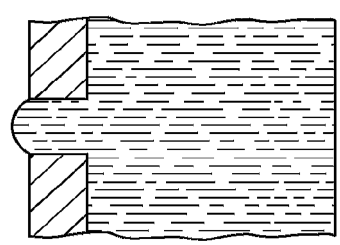


FIG. 6

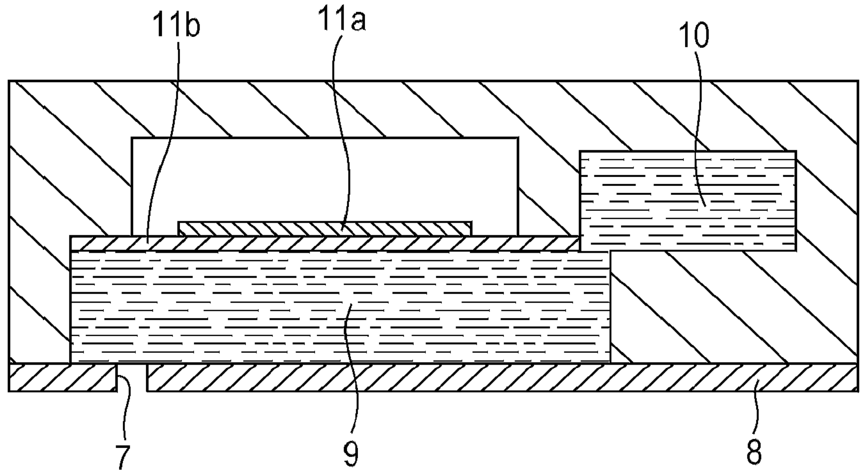


FIG. 7

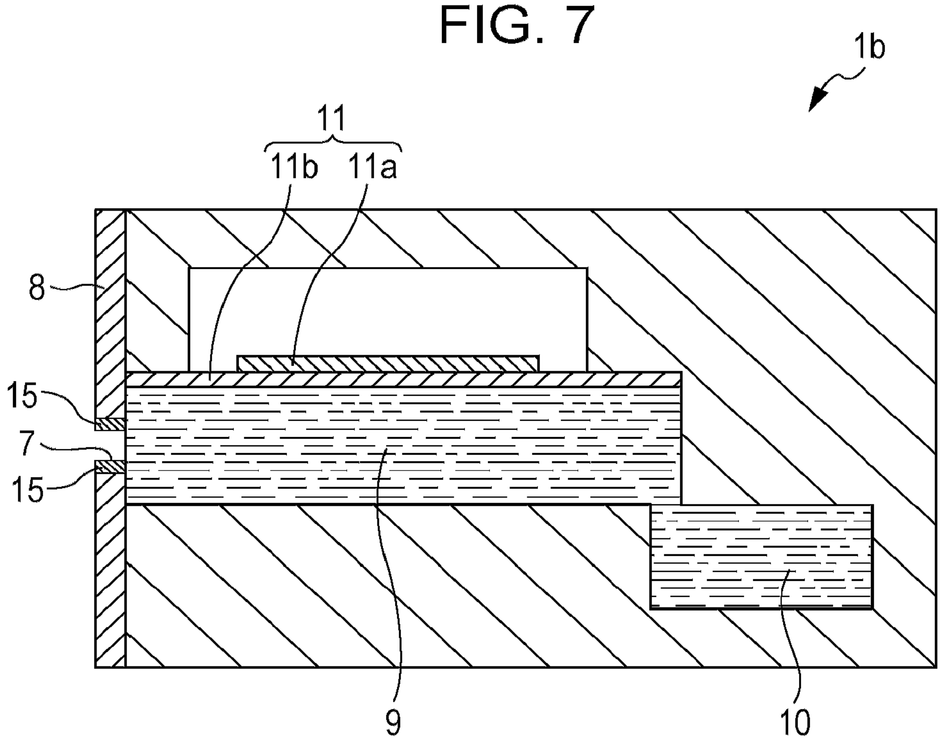


FIG. 8

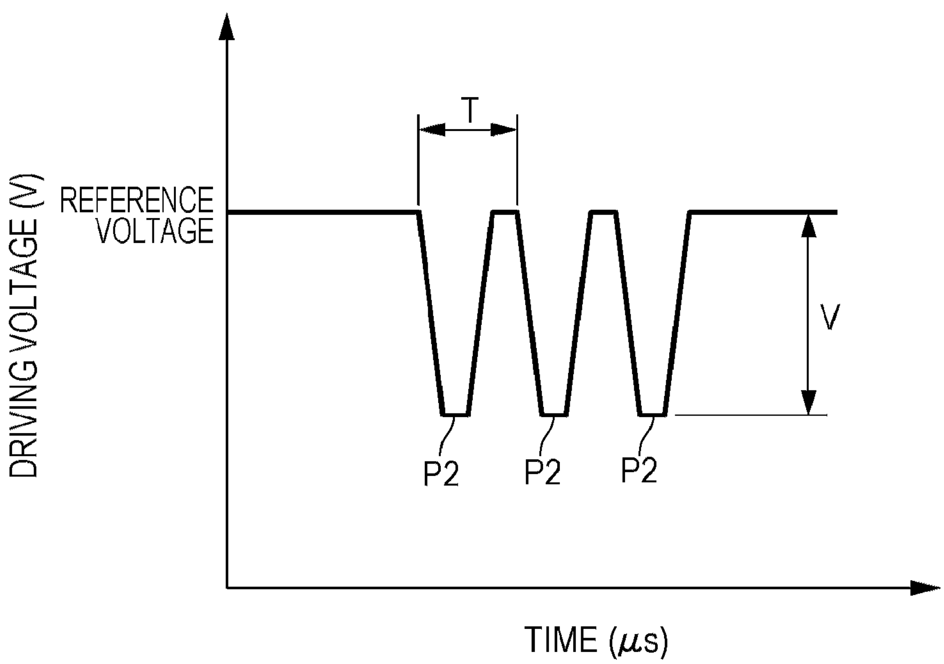


FIG. 9A

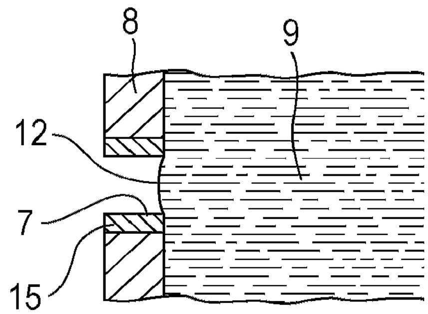


FIG. 9D

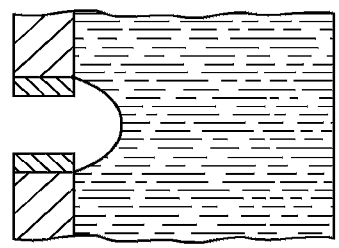


FIG. 9B

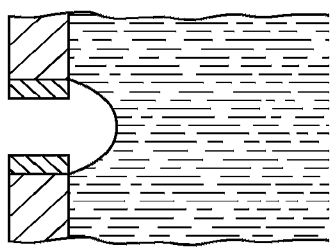


FIG. 9E

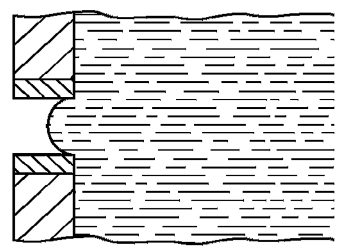
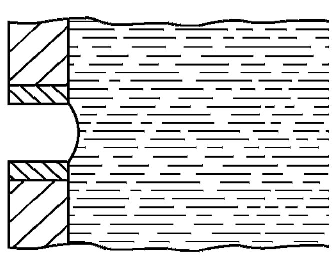


FIG. 9C



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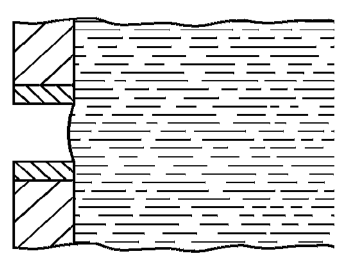


FIG. 10

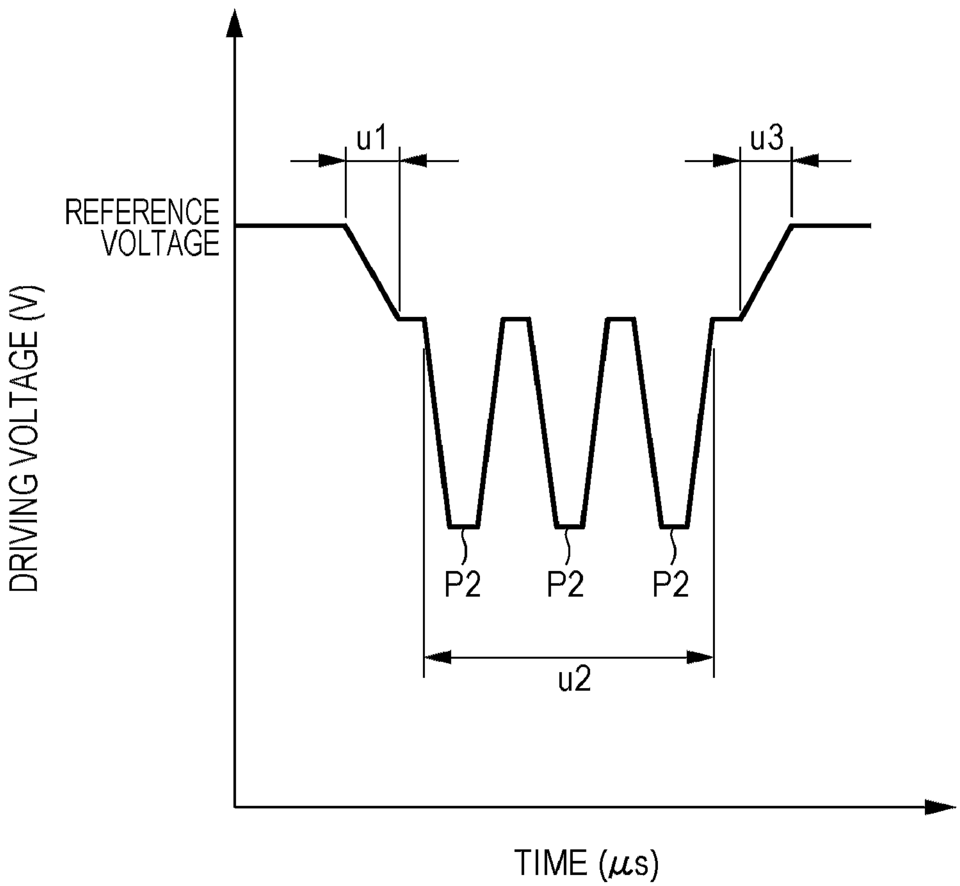


FIG. 11A

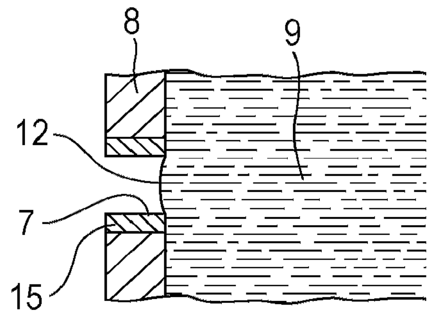


FIG. 11D

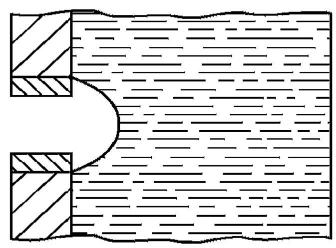


FIG. 11B

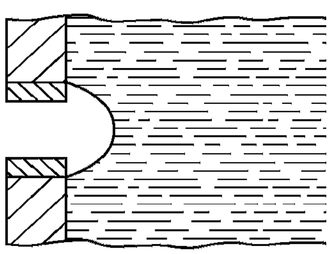
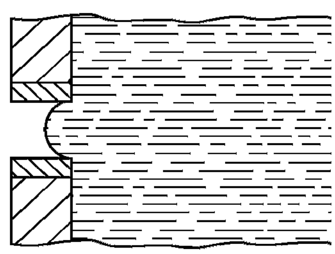


FIG. 11E



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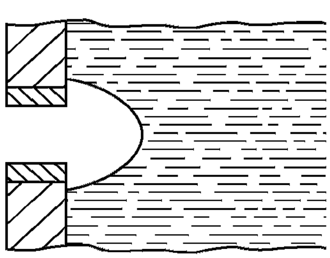

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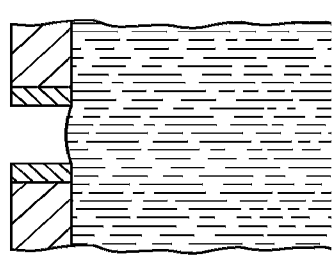


FIG. 12

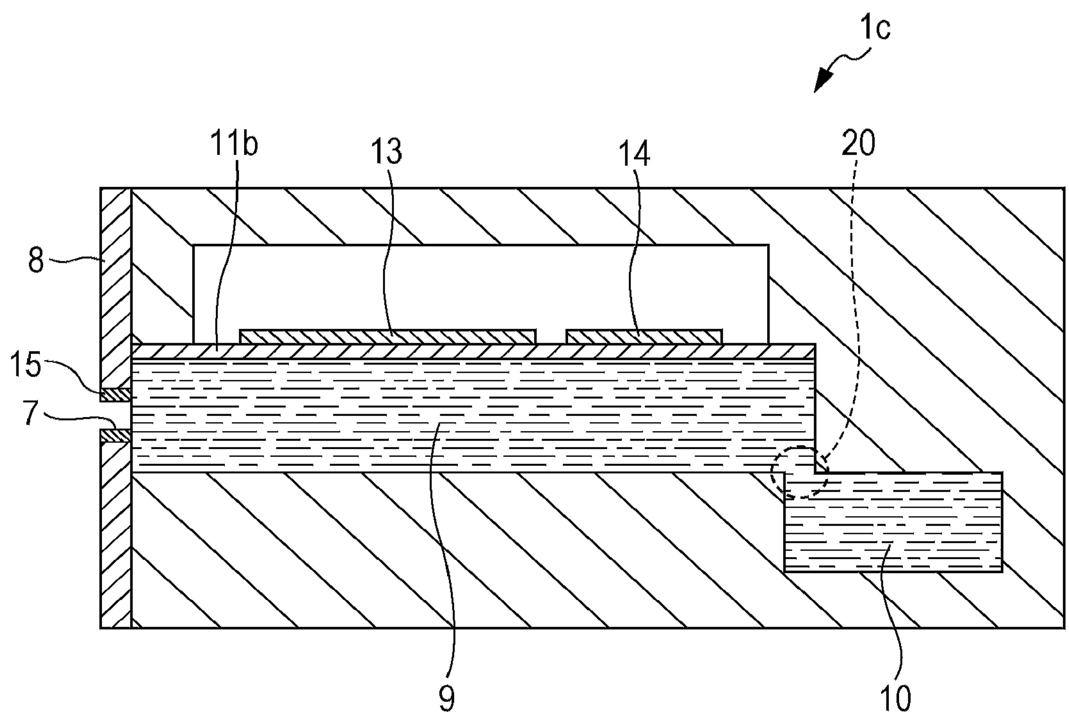


FIG. 13

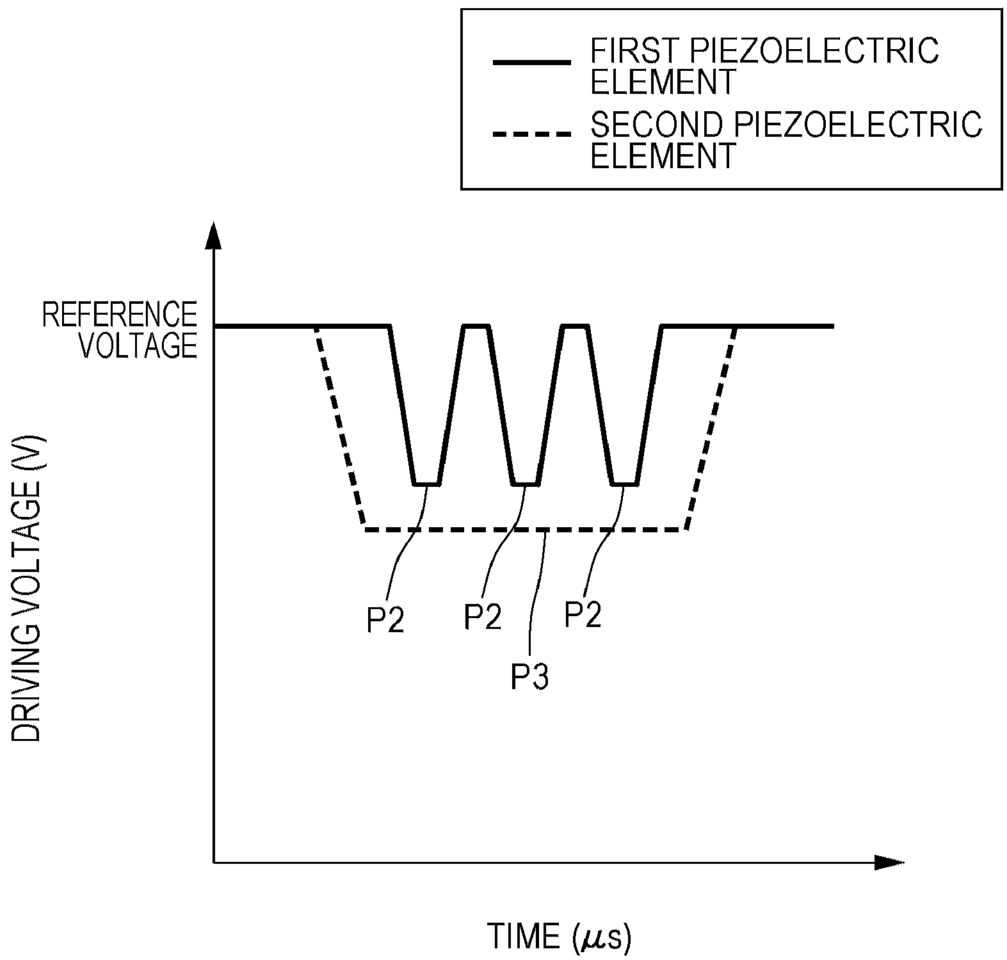

FIRST PIEZOELECTRIC ELEMENT
SECOND PIEZOELECTRIC ELEMENT
REFERENCE VOLTAGE
DRIVING VOLTAGE (V)
P2
P2
P2
P3
TIME (μs)

FIG. 14A

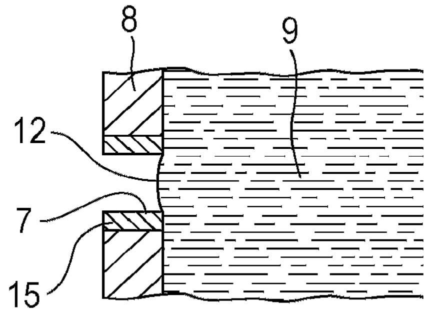
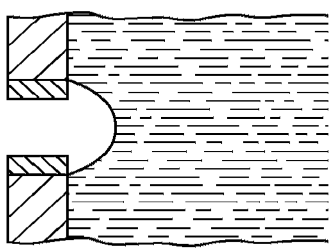


FIG. 14B



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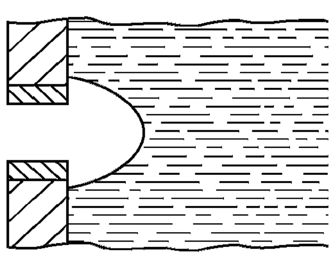
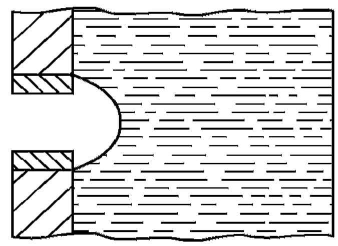


FIG. 14D



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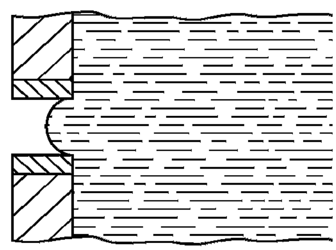

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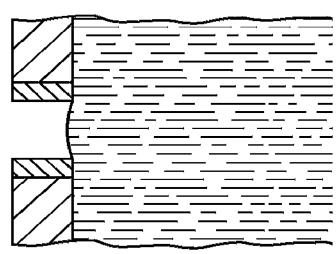


FIG. 15

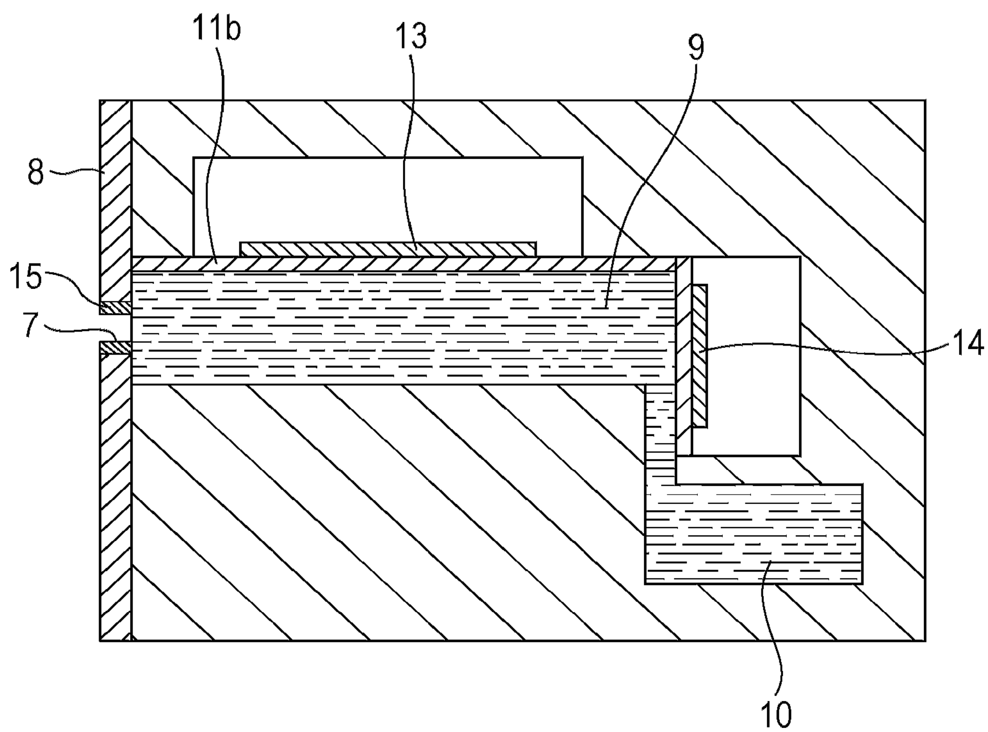


FIG. 16A

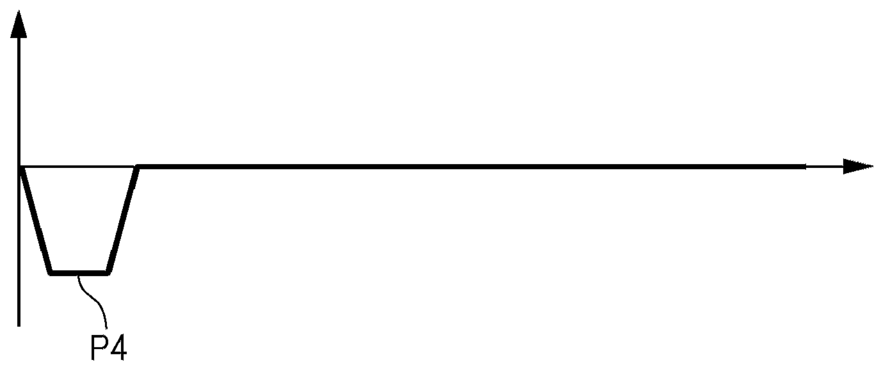


FIG. 16B

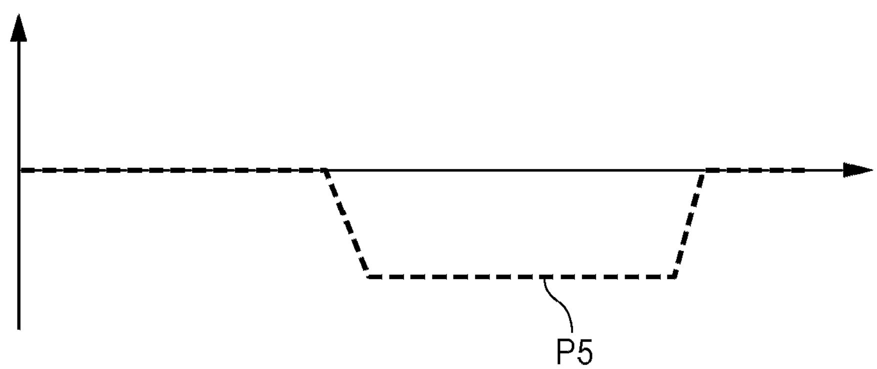


FIG. 17A

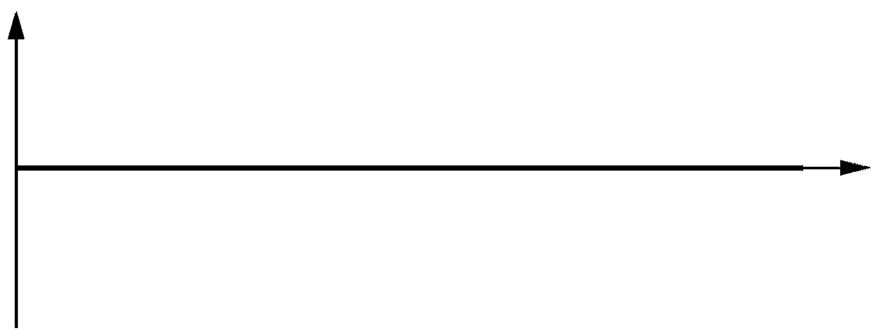


FIG. 17B

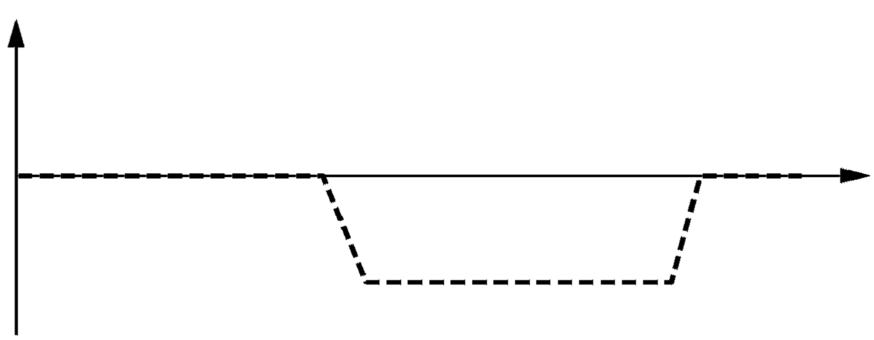


FIG. 18A

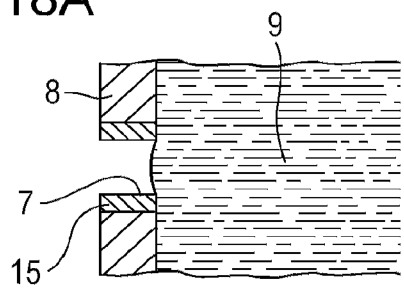
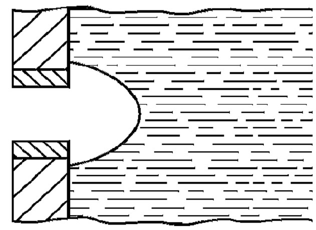


FIG. 18E



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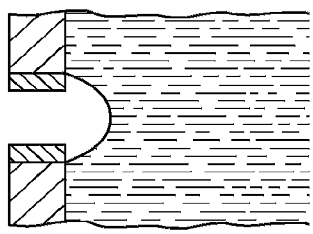


FIG. 18F

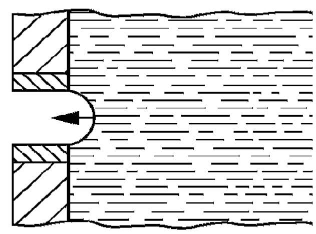


FIG. 18C

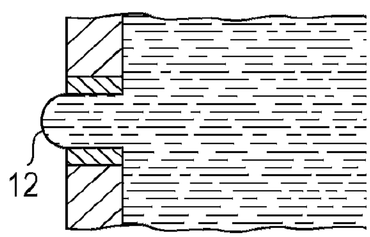


FIG. 18G

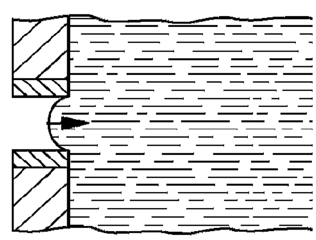


FIG. 18D

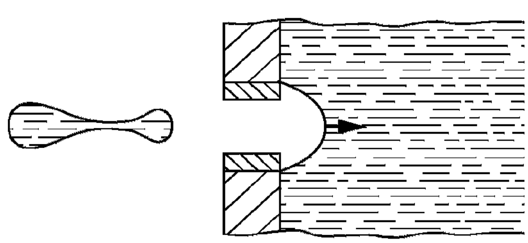


FIG. 18H

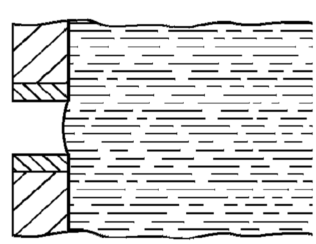


FIG. 19A

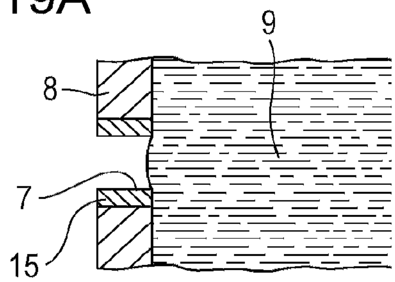


FIG. 19B

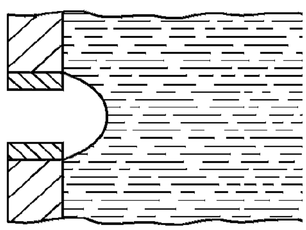


FIG. 19C

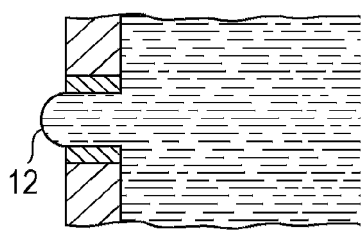


FIG. 19D

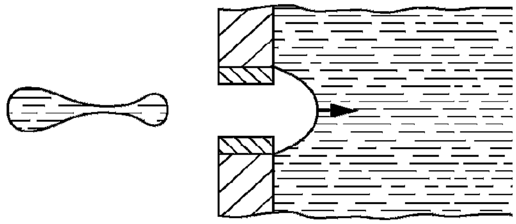


FIG. 19E

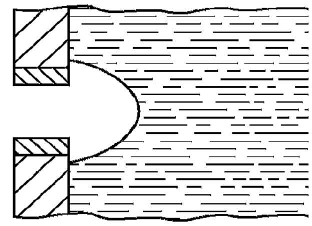


FIG. 19F

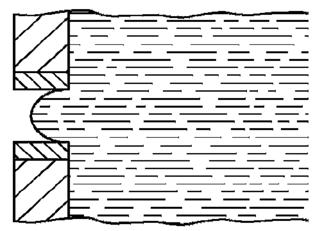


FIG. 19G

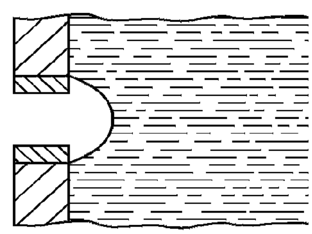


FIG. 19H

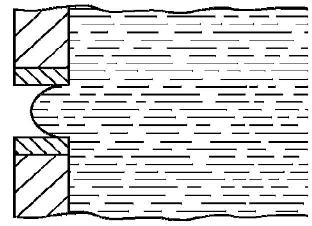


FIG. 20A

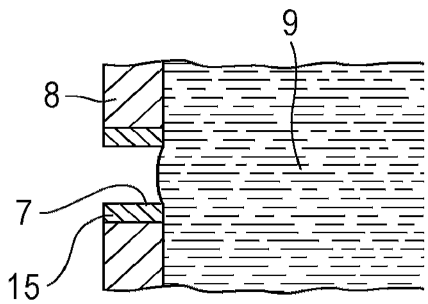


FIG. 20D

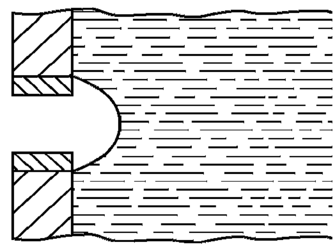


FIG. 20B

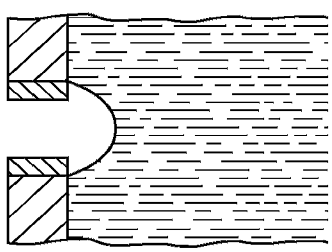


FIG. 20E

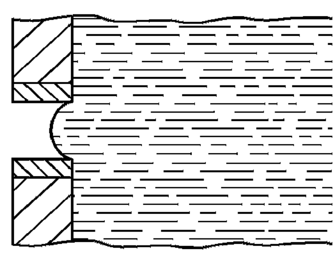


FIG. 20C

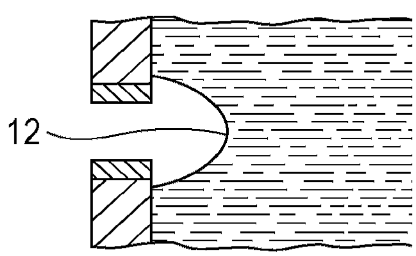
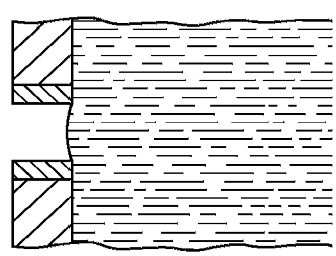


FIG. 20F



LIQUID EJECTION HEAD AND METHOD OF DRIVING THE SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a liquid ejection head configured to eject liquid using a piezoelectric actuator, and a method of driving such a liquid ejection head.

2. Description of the Related Art

In recent years, in ink-jet recording technology, to suppress deformation of paper such as curling or cockling caused by a water content of ink, a technique has been investigated to eject high-viscosity ink with a low water content. In the ink-jet recording, an increase occurs in viscosity of ink located close to an ejection orifice of a nozzle that has not been used to eject ink for a long period. The increase in viscosity of ink can cause the ejection orifice to be clogged, which can cause a reduction in ejection performance or even an ejection failure. This phenomenon tends to occur in particular when the ink used is high in viscosity and contains a large amount of colorant or the like per unit volume.

One of methods of preventing ejection orifices from being clogged is to use a meniscus vibration. In this method, a meniscus is slightly vibrated using an actuator thereby stirring ink with an increased viscosity located close to an ejection orifice. Specific techniques based on this method are disclosed in Japanese Patent No. 3613297 and Japanese Patent Laid-Open No. 2009-148927.

In the technique disclosed in Japanese Patent No. 3613297, a meniscus exposed outside an ejection orifice is vibrated by an actuator with a small amplitude at a particular frequency. On the other hand, in the technique disclosed in Japanese Patent Laid-Open No. 2009-148927, a meniscus adjuster such as an electric syringe is used to first draw a meniscus in an ejection orifice in an inward direction by depressurizing a liquid chamber communicating with the ejection orifice and then vibrate the meniscus with a small amplitude.

In the technique disclosed in Japanese Patent No. 3613297, the meniscus is vibrated in a state in which the meniscus is exposed to the outside of the ejection orifice, and thus there is a possibility that ink is incorrectly ejected or scattered. Therefore, in this technique, the vibration of the meniscus is limited to that with a small amplitude. The high-viscosity ink tends to easily increase in viscosity, and thus the small amplitude of vibration of the meniscus may not surely prevent the ejection orifice from being clogged. In the technique disclosed in Japanese Patent Laid-Open No. 2009-148927, the meniscus is vibrated such that the meniscus is first drawn to an inwardly displaced position and the vibration is performed at the displaced position, and thus it is possible to vibrate the meniscus with a large amplitude. Therefore, the technique disclosed in Japanese Patent Laid-Open No. 2009-148927 is capable of preventing the ejection orifice from being clogged with high-viscosity ink more effectively than can be by the technique disclosed in Japanese Patent No. 3613297. However, in the technique disclosed Japanese Patent Laid-Open No. 2009-148927, in addition to the piezoelectric element for ejecting ink, the meniscus adjuster is disposed in a flow path between the ink tank and the recording head. The necessity of the additional provision of the meniscus adjuster results in an increase in complexity and size of the apparatus.

SUMMARY OF THE INVENTION

According to an aspect of the present invention, a liquid ejection head includes a plurality of ejection orifices, wherein each ejection orifice is configured to eject liquid through the ejection orifice, a plurality of liquid chambers, wherein each liquid chamber is configured to communicate individually with a corresponding ejection orifice, a plurality of piezoelectric actuators, wherein each piezoelectric actuator is disposed individually for a corresponding liquid chamber and configured to generate energy to eject liquid through the corresponding ejection orifice, a plurality of driving units, wherein each driving unit is configured to individually drive a corresponding piezoelectric actuator, and a control unit configured to control the plurality of driving units so that each driving unit outputs, to a corresponding piezoelectric actuator, a first voltage pulse or a second voltage pulse, wherein the first voltage pulse drives a corresponding piezoelectric actuator to eject liquid through the corresponding ejection orifice and the second voltage pulse drives a corresponding piezoelectric actuator to vibrate a corresponding meniscus of liquid such that the meniscus vibrates in the corresponding liquid chamber in a state in which the meniscus is held in the liquid chamber, and wherein the control unit selects, from the plurality of ejection orifices, one or more ejection orifices used to eject liquid and controls driving units corresponding to the selected ejection orifices such that these driving units output the first voltage pulse to thereby perform a recording operation, and the control unit controls driving units corresponding to ejection orifices that are not used to eject liquid such that these driving units output the second voltage pulse to thereby perform a recovery operation concurrently with the recording operation.

According to another aspect of the invention, a method of driving a liquid ejection head includes preparing the liquid ejection head including a plurality of ejection orifices, wherein each ejection orifice is configured to eject liquid through the ejection orifice, a plurality of liquid chambers, wherein each liquid chamber is configured to communicate individually with a corresponding ejection orifice, and a plurality of piezoelectric actuators, wherein each piezoelectric actuator is disposed individually for a corresponding liquid chamber and configured to operate such that, in response to a first voltage pulse being applied, each piezoelectric actuator ejects liquid through the corresponding ejection orifice and, in response to a second voltage pulse being applied, each piezoelectric actuator vibrates a corresponding meniscus of liquid such that the meniscus vibrates in the corresponding liquid chamber in a state in which the meniscus is held in the liquid chamber, performing a first step including selecting, from the plurality of ejection orifices, one or more ejection orifices used to eject liquid and applying the first voltage pulse to piezoelectric actuators corresponding to the selected ejection orifices, and performing a second step concurrently with the first step, the second step including applying the second voltage pulse to piezoelectric actuators corresponding to ejection orifices that are not used to eject liquid.

Further features of the present invention will become apparent from the following description of exemplary embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram illustrating a configuration of main parts of an ink-jet recording apparatus including a liquid ejection head according to a first embodiment.

FIG. **2**A and FIG. **2**B are diagrams illustrating a structure of a liquid ejection head according to the first embodiment.

FIG. **3** is a block diagram illustrating a process of electrically controlling the liquid ejection head shown in FIG. **2**A and FIG. **2**B.

FIG. **4** is a graph illustrating waveforms of voltage pulses used to drive the liquid ejection head shown in FIG. **2**A and FIG. **2**B.

FIGS. **5**A to **5**F are diagrams illustrating behavior of a meniscus of ink in the liquid ejection head shown in FIG. **2**A and FIG. **2**B.

FIG. **6** is a cross-sectional view illustrating another structure of a liquid ejection head according to an embodiment.

FIG. **7** is a cross-sectional view illustrating a structure of a liquid ejection head according to a second embodiment.

FIG. **8** is a graph illustrating a waveform of a voltage pulse used to drive the liquid ejection head shown in FIG. **7**.

FIGS. **9**A to **9**F are diagrams illustrating behavior of a meniscus of ink in the liquid ejection head shown in FIG. **7**.

FIG. **10** is a graph illustrating a driving voltage pulse waveform used to drive a liquid ejection head according to a third embodiment.

FIGS. **11**A to **11**F are diagrams illustrating behavior of a meniscus of ink in a liquid ejection head according to the third embodiment.

FIG. **12** is a cross-sectional view illustrating a structure of a liquid ejection head according to a fourth embodiment.

FIG. **13** is a graph illustrating waveforms of voltage pulses used to drive the liquid ejection head shown in FIG. **12**.

FIGS. **14**A to **14**F are diagrams illustrating behavior of a meniscus of ink in the liquid ejection head shown in FIG. **12**.

FIG. **15** is a cross-sectional view illustrating a liquid ejection head having a structure modified from that shown in FIG. **12**.

FIGS. **16**A and **16**B are graphs illustrating waveforms of voltage pulses applied to a nozzle used to eject ink in a liquid ejection head according to a fifth embodiment.

FIGS. **17**A and **17**B are graphs illustrating waveforms of voltage pulses applied to a nozzle that is not used to eject ink in the liquid ejection head according to the fifth embodiment.

FIGS. **18**A to **18**H are diagrams illustrating behavior of an ink meniscus in a nozzle that is used to eject ink in the liquid ejection head according to the fifth embodiment.

FIGS. **19**A to **19**H are diagrams illustrating behavior of a meniscus that would occur if a voltage pulse were not applied to a second piezoelectric element in the liquid ejection head according to the fifth embodiment.

FIGS. **20**A to **20**F are diagrams illustrating behavior of an ink meniscus in a nozzle that is not used to eject ink in the liquid ejection head according to the fifth embodiment.

DESCRIPTION OF THE EMBODIMENTS

First Embodiment

FIG. **1** illustrates a configuration of main parts of an ink-jet recording apparatus including a liquid ejection head according to a first embodiment. In the ink-jet recording apparatus shown in FIG. **1**, a recording medium **2** is placed on a conveying belt **4** with an endless shape stretched between conveying rollers **3**, and the conveying belt **4** is driven to convey the recording medium **2** in a conveying direction (represented by an arrow X). As shown in FIG. **1**, the ink-jet recording apparatus includes four liquid ejection heads **1***a* to which ink is supplied from ink tanks **6** via pumps **5**. Each liquid ejection head **1***a* is configured to handle ink of specified one of four colors including yellow (Y), magenta (M), cyan (C), and black (Bk), and liquid ejection heads **1***a* are arranged in the same direction as the conveying direction of the recording medium **2**. Full-color recording is performed by ejecting color ink from the liquid ejection heads **1***a* while conveying the recording medium **2** in the conveying direction.

FIGS. **2**A and **2**B illustrate a structure of the liquid ejection head according to the present embodiment. FIG. **2**A is a plan view of the liquid ejection head **1***a* seen from the side of the ink ejection orifices. FIG. **2**B is a cross-sectional view taken along line IIB-IIB of FIG. **2**A. FIG. **3** is a block diagram illustrating a process of electrically controlling the liquid ejection head shown in FIG. **2**A and FIG. **2**B.

In the present embodiment, as shown in FIG. **2**A, each liquid ejection head **1***a* includes an ejection orifice plate **8** having a plurality of ejection orifices **7**. The ejection orifices **7** are arranged depending on the width of the recording medium **2**. In the present embodiment, each ejection orifice **7** is a circular orifice with a diameter (d) of 17 μm (see FIG. **2**A). The ejection orifice plate **8** has a thickness (t) of 17 μm (see FIG. **2**B).

Each ejection orifice **7** individually communicates with a liquid chamber **9**. Each liquid chamber **9** has a length (L) of 6000 μm, a width (W) of 100 μm, and a height (H) of 200 μm (see FIG. **2**B). Each liquid chamber **9** communicates with a common liquid chamber **10** via a narrowed part **20** with a width of 30 μm.

On a wall of the liquid chamber **9**, there is provided a piezoelectric actuator **11** that generates energy to eject liquid (ink) through the ejection orifice **7**. In the present embodiment, the piezoelectric actuator **11** includes a bend-mode piezoelectric element **11***a* and a vibrating plate **11***b* on which the piezoelectric element **11***a* is disposed. The piezoelectric element **11***a* is driven by a driving unit **21** (see FIG. **3**). Under the control of a control unit **31** (see FIG. **3**), the driving unit **21** outputs a voltage pulse P**1** (first voltage pulse (see FIG. **4**)) to the piezoelectric element **11***a* thereby to eject ink through the ejection orifice **7**. On receiving the voltage pulse P**1**, the piezoelectric element **11***a* drives the vibrating plate **11***b* such that the vibrating plate **11***b* is first bent in a direction to the inside of the liquid chamber **9** (as indicated by an arrow B in FIG. **2**B) and then returns into an initial state. This causes the liquid chamber **9** to contract, and, as a result, ink is ejected through the ejection orifice **7** and recording is performed. In the present embodiment, by way of example, clear ink (containing 66% of PEG 600, 33% of pure water, and 1% of surfactant) with a viscosity of 40×10^{-3} Pa·s (at chamber temperature) and a surface tension of 38×10^{-3} N/m (at chamber temperature) is used as the ink.

Next, an operation of the liquid ejection head **1***a* according to the present embodiment is described. FIG. **4** is a graph illustrating waveforms of driving voltage pulses used in the liquid ejection head **1***a* according to the present embodiment. In FIG. **4**, a horizontal axis represents time, and a vertical axis represents a driving voltage supplied to the piezoelectric element **11***a* from the driving unit **21**.

If a recording information representing content to be recorded is input from the main part of the ink-jet recording apparatus to the control unit **31**, then the control unit **31** selects ejection orifices used to eject ink from the plurality of ejection orifices **7** based on the input recording information. The control unit **31** then controls driving units **21** corresponding to the selected ejection orifices to output the voltage pulse P**1** to the corresponding piezoelectric elements **11***a* thereby to perform the recording operation.

In parallel to the recording operation described above, the control unit **31** controls driving units **21** corresponding to ejection orifices that are not used to eject ink such that the driving units **21** supply a second voltage pulse to the corresponding piezoelectric elements **11***a* thereby to perform a recovery operation in which the ink in the liquid chamber **9** is stirred. The recovery operation and the behavior of the meniscus **12** of ink during the recovery operation are described below. FIGS. **5**A to **5**F illustrate behavior of the meniscus **12** of ink in the liquid ejection head according to the present embodiment.

In an initial state before the recovery operation is performed, the meniscus **12** of ink is located at the outer end of the ejection orifice **7** and within the ejection orifice **7** (see FIG. **5**A). In a first period t**1** (see FIG. **4**) in the recovery operation, under the control of the control unit **31**, the driving unit **21** applies a voltage lower than a reference voltage to the piezoelectric element **11***a* such that the vibrating plate **11***b* is deformed so as to be bent in a direction to the outside of the liquid chamber **9** (as indicated by an arrow C in FIG. **2**B), thereby expanding the liquid chamber **9**. The expansion of the liquid chamber **9** causes the meniscus **12** to be drawn from the ejection orifice **7** into the inside of the liquid chamber **9** (see FIG. **5**B).

In a period t**2** (see FIG. **4**), to prevent the meniscus **12** from returning back to the ejection orifice **7**, the driving unit **21** applies, to the piezoelectric element **11***a*, a voltage lower than the voltage applied during the period t**1** (see FIG. **4**) such that the liquid chamber **9** continues to gradually expand and the meniscus **12** remains within the liquid chamber **9** (see FIG. **5**C).

In a period t**3** (see FIG. **4**), the driving unit **21** supplies a voltage pulse P**2** to the piezoelectric element **11***a* a plurality of times successively (see FIG. **4**). Each time the voltage pulse P**2** is applied to the piezoelectric element **11***a*, the vibrating plate **11***b* moves in a direction to the outside of the liquid chamber **9** (as represented by an arrow C in FIG. **2**B) and returns back to its original position (i.e., the vibrating plate **11***b* vibrates). In response to the outward/backward movement of the vibrating plate **11***b*, the meniscus **12** vibrates (see FIG. **5**C to FIG. **5**E).

In a period t**4** (see FIG. **4**), the liquid chamber **9** is contracted such that the liquid chamber **9** returns into its original state and the meniscus **12** returns into its initial state. The meniscus **12** goes to the outside of the ejection orifice **7** beyond its original position (see FIG. **5**F) and then returns to its original position (shown in FIG. **5**A). In the present embodiment, as described above, the ejection for recording and the operation for recovery are performed using a simple mechanism including the piezoelectric actuator **11**. Use of the actuator **11** instead of a pump or the like to vibrate the meniscus makes it possible to achieve quick response in vibrating the meniscus because the actuator **11** is located close to the ejection orifice where the meniscus is formed.

Furthermore, in the present embodiment, the recovery operation in which the voltage pulse P**2** is output by the driving units **21** corresponding to the ejection orifices **7** that are not used to eject ink is performed concurrently with the recording operation in which the voltage pulse P**1** is output by the driving units **21** corresponding to the ejection orifices **7** that are used to eject ink. Therefore, during the recording operation, it is possible to stir the ink in liquid chambers **9** communicating with the ejection orifices **7** that are not used to eject ink, which makes it possible to ejection orifices **7** from being clogged even if there is a nozzle that is not used for a long period. Furthermore, it is possible to vibrate the meniscus **12** while keeping the location of the meniscus **12** in the liquid chamber **9**, and thus it is possible to effectively recover the ejection orifices **7** from the clogged state by greatly vibrating the meniscus **12** without causing liquid to be ejected. Therefore, even when the ink used has a high viscosity, it is possible to prevent the ejection orifice **7** from being clogged.

Furthermore, in the present embodiment, the piezoelectric actuator **11** has two functions, i.e., the function of ejecting ink and the function of stirring ink in the liquid chamber **9** (thereby vibrating the meniscus **12**). Therefore, an additional special part is not necessary to prevent the ejection orifice **7** from being clogged with ink, and thus high cost performance can be achieved.

In the present embodiment, the liquid ejection head **1***a* is of an edge shooter type in which the ejection orifice **7** is formed in a direction in which the liquid chamber **9** extends (i.e., in a direction in which ink flows) as shown in FIG. **2**B. Alternatively, the liquid ejection head **1***a* may be of a side shooter type in which the ejection orifice **7** is formed in a direction perpendicular to the direction in which the liquid chamber **9** extends as shown in FIG. **6**.

In the present embodiment, the bend-mode piezoelectric element is used as the piezoelectric element **11***a*. Alternatively, other types such as a push-mode type, a share-mode type, or a Gould type may be used as the piezoelectric element **11***a*.

Second Embodiment

FIG. **7** is a cross-sectional view illustrating a structure of a liquid ejection head **1***b* according to a second embodiment. In FIG. **7**, similar elements to those of the liquid ejection head **1***a* according to the first embodiment are denoted by similar reference numerals and a further detailed description thereof is omitted.

In the liquid ejection head **1***b* according to the present embodiment, as shown in FIG. **7**, a liquid-repellent layer **15** that is repellent to ink is formed on an inner wall of an ejection orifice **7**.

Also in the present embodiment as in the first embodiment, a recovery operation is performed. The recovery operation of the liquid ejection head **1***a* according to the present embodiment and the behavior of the meniscus **12** of ink during the recovery operation are described below. FIG. **8** is a graph illustrating a waveform of a voltage pulse used to drive the liquid ejection head **1***b* according to the present embodiment. In FIG. **8**, a horizontal axis represents time, and a vertical axis represents a driving voltage supplied to a piezoelectric element **11***a* from a driving unit **21**. FIGS. **9**A to **9**F illustrate behavior of the meniscus **12** of ink in the liquid ejection head **1***b* according to the present embodiment.

In an initial state before the recovery operation is performed, the provision of the liquid-repellent layer **15** formed on the inner wall of the ejection orifice **7** ensures that the meniscus **12** is kept at an inner opening end, at the boundary with the liquid chamber, of the ejection orifice **7** (see FIG. **9**A). First, the driving unit **21** outputs a trapezoidal-waveform voltage pulse P**2** to the piezoelectric element **11***a*. In response to the voltage pulse P**2** applied to the piezoelectric element **11***a*, the vibrating plate **11***b* vibrates in a direction to the outside of the liquid chamber **9**. This causes the meniscus **12** is first drawn into the liquid chamber **9** and then returns to its original position (see FIG. **9**B and FIG. **9**C). When a next voltage pulse P**2** is applied, the meniscus **12** is again drawn into the liquid chamber **9** (see FIG. **9**D). In the present embodiment, the vibration is performed repeatedly three times. The vibration of the meniscus **12** enhances diffusion of colorants or a surfactant and destroys a film of a colorant or a surfactant.

When the third-time application of the voltage pulse P**2** is ended, the meniscus **12** is moved from the common liquid chamber **10** to the ejection orifice **7** by a flow of ink (see FIG. **9**E) and the meniscus **12** finally returns into the initial state shown in FIG. **9**F.

In the present embodiment, the voltage pulse P**2** with a repetition period (T) of 2 μs (see FIG. **8**) and an amplitude (V) of 15 volts (see FIG. **8**) is applied to the piezoelectric element **11***a* thereby to vibrate the meniscus **12** with an amplitude of about 14 μm, which can recover the ejection orifice **7** of the nozzle from the clogged state caused by the increase in viscosity of ink.

The voltage pulse P**2** used in the present embodiment has a repetition period (T) of 2 μs which corresponds to a frequency of 50 kHz. The higher the frequency of the vibration of the meniscus **12**, the more effectively the nozzle can be recovered. From this point of view, the frequency of the voltage pulse P**2** may be set to be several tens kHz or higher.

In the present embodiment, the provision of the liquid-repellent layer **15** formed on the inner wall of the ejection orifice **7** prevents the meniscus **12** from being incorrectly ejected from the ejection orifice **7** or scattered even when the meniscus **12** is vibrated greatly in the recovery operation.

Third Embodiment

A liquid ejection head according to a third embodiment is described below. The liquid ejection head according to the present embodiment has a similar structure to that of the liquid ejection head **1***b* according to the second embodiment. The details of the liquid ejection head **1***b* according to the third embodiment are described below while focusing on differences from that according to the second embodiment.

FIG. **10** is a graph illustrating a waveform of a driving voltage pulse used in the liquid ejection head **1***b* according to the present embodiment. In FIG. **10**, a horizontal axis represents time, and a vertical axis represents a driving voltage supplied to the piezoelectric element **11***a* from the driving unit **21**. FIGS. **11**A to **11**F illustrate behavior of a meniscus of ink in the liquid ejection head **1***b* according to the present embodiment.

In an initial state before a recovery operation is started, presence of a liquid-repellent layer **15** formed on an inner wall of an ejection orifice **7** causes the meniscus **12** to be held at an inner opening end, at the boundary with the liquid chamber **9**, of the ejection orifice **7** (see FIG. **11**A) as in the second embodiment.

In a period u**1** (see FIG. **10**) in the recovery operation, the driving unit **21** applies a voltage lower than a reference voltage to the piezoelectric element **11***a* whereby the liquid chamber **9** is expanded. As a result, the meniscus **12** is drawn further into the inside of the liquid chamber **9** (see FIG. **11**B).

In a period u**2** (see FIG. **10**) following the period u**1**, the driving unit **21** supplies a voltage pulse P**2** to the piezoelectric element **11***a* three times successively thereby to vibrate the meniscus **12** (see FIG. **11**B to FIG. **11**D).

In a period u**3** (see FIG. **10**) following the period u**2**, the liquid chamber **9** is contracted such that the liquid chamber **9** returns into its original state and the meniscus **12** returns into its initial state. The meniscus **12** is moved from the common liquid chamber **10** to the ejection orifice **7** by a flow of ink (see FIG. **11**E) and the meniscus **12** finally returns into its initial state (see FIG. **11**F).

In the present embodiment, the meniscus **12** is first drawn from an inner opening end, at the boundary with the liquid chamber **9**, of the ejection orifice **7** to the position displaced to the inside of the liquid chamber **9**, and then the meniscus **12** is vibrated at the displaced position. This further reduces the probability that ink is incorrectly ejected or scattered, and thus it becomes possible to vibrate the meniscus **12** with a large amplitude. The large-amplitude vibration makes it possible to more effectively recover the ejection orifice **7** of the nozzle from the clogged state caused by the increase in viscosity of ink.

Fourth Embodiment

FIG. **12** is a cross-sectional view illustrating a structure of a liquid ejection head according to a fourth embodiment. In FIG. **12**, similar elements to those of the liquid ejection head according to the previous embodiment are denoted by similar reference numerals and a further detailed description thereof is omitted.

The liquid ejection head **1***c* according to the present embodiment includes a first piezoelectric element **13** and a second piezoelectric element **14** disposed on the vibrating plate **11***b* such that the second piezoelectric element **14** is located farther away from the ejection orifice **7** than the first piezoelectric element **13** is located. In the present embodiment, the first piezoelectric element **13** and the second piezoelectric element **14** are both bend-mode piezoelectric elements as with the piezoelectric element **11***a* described above. The first piezoelectric element **13** and the second piezoelectric element **14** are driven by separate driving units **21**. A liquid-repellent layer **15** is formed on an inner wall of the ejection orifice **7**. The each liquid chamber **9** has a length of 9000 μm, while the width and the height thereof are equal to those according to the previous embodiments. Each liquid chamber **9** communicates with a common liquid chamber **10** via a narrowed part **20** with a width of 50 μm.

Also in the present embodiment as in the previous embodiments, a recovery operation is performed concurrently with a recording operation. The recovery operation of the liquid ejection head according to the present embodiment and the behavior of the meniscus of ink during the recovery operation are described below. FIG. **13** is a graph illustrating a driving voltage pulse waveform used to drive the liquid ejection head **1***c* according to the present embodiment. In FIG. **13**, a horizontal axis represents time, and a vertical axis represents driving voltages supplied to a first piezoelectric element **13** and second piezoelectric element **14**. FIGS. **14**A to **14**F illustrate behavior of a meniscus of ink in the liquid ejection head **1***c* according to the present embodiment.

In an initial state before the recovery operation is performed, the provision of the liquid-repellent layer **15** formed on the inner wall of the ejection orifice **7** ensures that the meniscus **12** is kept at the inner opening end, at the boundary with the liquid chamber **9**, of the ejection orifice **7** (see FIG. **14**A). First, one driving unit **21** outputs a voltage pulse P**3** (third voltage pulse) to the second piezoelectric element **14**. In response, the liquid chamber **9** starts to expand and the meniscus **12** is drawn further into the inside of the liquid chamber **9** (see FIG. **14**B). Thereafter, the other driving unit **21** outputs a voltage pulse P**2** to the first piezoelectric element **13**. In response, the meniscus **12** vibrates (see FIG. **14**B to FIG. **14**D). When the applying of the voltage pulse P**3** with a pulse width greater than that of the second voltage pulse is ended, the liquid chamber **9** contracts into its original state and the meniscus **12** returns into its initial state. In this process, the meniscus **12** is moved from the common liquid chamber **10** to the ejection orifice **7** by a flow of ink (see FIG. **14**E) and the meniscus **12** finally returns into the initial state (see FIG. **14**F).

In the present embodiment, when the voltage pulse P**2** with a period of 5 μs and an amplitude of 35 volts is applied to the first piezoelectric element **13**, the meniscus **12** vibrates with an amplitude of about 25 μm, which can recover the ejection orifice **7** of the nozzle from the clogged state caused by the increase in viscosity of ink.

In the present embodiment, the operation of drawing the meniscus **12** and the operation of vibrating the meniscus **12** are performed using different piezoelectric elements. This makes it possible to reduce the voltage pulse to a lower level than is allowed in the previous embodiments in which the same actuator is used to perform both operations. This allows a reduction in load on the piezoelectric elements, which results in an increase in operation life. Furthermore, it is possible to reduce the size of each piezoelectric element. The reduction in size results in an increase in natural frequency of the piezoelectric element, which makes it possible to apply a greater vibration to the ink in the liquid chamber **9**.

In the present embodiment, bend-mode piezoelectric elements are used as the first piezoelectric element **13** and the second piezoelectric element **14**. Alternatively, other types of piezoelectric elements such as a push-mode type, a share-mode type, a Gould type, etc., may be used.

In the present embodiment, the first piezoelectric element **13** and the second piezoelectric element **14** are disposed in a line. Alternatively, they may be disposed in planes perpendicular to each other as shown in FIG. **15**.

Fifth Embodiment

A liquid ejection head according to a fifth embodiment is described below. The liquid ejection head according to the present embodiment has a similar structure to that of the liquid ejection head **1***c* according to the fourth embodiment (see FIG. **12**). In the following description, similar elements to those of the liquid ejection head according to the previous embodiment are denoted by similar reference numerals and a further detailed description thereof is omitted.

The present embodiment provides a mechanism that is based on a simple method and that can prevent a residual vibration from occurring in a nozzle used to eject ink and can prevent clogging due to an increase in viscosity of ink from occurring in an ejection orifice **7** in a nozzle that is not used to eject ink.

Also in the present embodiment as in the previous embodiments, a recovery operation is performed in parallel to a recording operation. Referring to FIGS. **18**A to **18**H and FIGS. **19**A to **19**H, the recovery operation of the liquid ejection head according to the present embodiment and the behavior of the meniscus **12** of ink during the recovery operation are described below. FIG. **16**A is a graph illustrating a waveform of a driving voltage pulse applied to a first piezoelectric element **13** of a nozzle used to eject ink in a recording operation using a liquid ejection head **1***c* according to the present embodiment. FIG. **16**B is a graph illustrating a waveform of a driving voltage pulse applied to a second piezoelectric element **14** of the nozzle used to eject ink in the recording operation. FIG. **17**A is a graph illustrating a waveform of a driving voltage pulse applied to a first piezoelectric element **13** of a nozzle that is not used to eject ink. FIG. **17**B is a graph illustrating a waveform of a driving voltage pulse applied to a second piezoelectric element **14** of the nozzle that is not used to eject ink. In each of FIGS. **16**A and **16**B and FIGS. **17**A and **17**B, a horizontal axis represents time, and a vertical axis represents driving voltages supplied to the first piezoelectric element **13** and the second piezoelectric element **14**. FIGS. **18**A to **18**H illustrate behavior of the meniscus **12** of ink in a nozzle used to eject ink in the operation using the liquid ejection head **1***c* according to the present embodiment. FIGS. **19**A to **19**H illustrate behavior of the meniscus **12** of ink which would occur if the driving voltage pulse with the waveform shown in FIG. **16**B were not applied to the second piezoelectric element **14** of the nozzle used to eject ink. FIGS. **20**A to **20**F are diagrams illustrating behavior of the meniscus **12** of ink in a nozzle that is included in the liquid ejection head **1***c* but that is not used to eject ink, according to the present embodiment.

Referring to FIGS. **16**A and **16**B and FIGS. **18**A to **18**H, the behavior of the meniscus **12** of ink in the nozzle used to eject ink is described below. In these figures, broken lines represent the behavior of the meniscus **12** when the voltage pulse P**5** (fifth voltage pulse) is not input.

First, to eject ink, the driving unit **21** shown in FIG. **3** outputs a voltage pulse P**4** (fourth voltage pulse) used to drive the first piezoelectric element **13** shown in FIG. **12** to eject ink (see FIG. **16**A). In response, the ink is ejected from the ejection orifice **7** (see FIG. **18**D).

Thereafter, after the meniscus **12** has returned to the original position in the ejection orifice **7**, the driving unit **21** shown in FIG. **3** starts outputting a voltage pulse P**5** to the second piezoelectric element **14** (see FIG. **16**B). Note that the voltage pulse P**5** is applied such that the expanding of the liquid chamber **9** is started when the meniscus **12** is at the returned position in the ejection orifice **7** (see FIG. **18**F) and the contracting of the liquid chamber **9** is started when the meniscus **12** starts going backward by the residual vibration (see FIG. **18**G). That is, the voltage pulse P**5** is applied such that the liquid chamber **9** is expanded or contracted against the motion of the meniscus **12** thereby to suppress the residual vibration of the meniscus **12**.

If the voltage pulse P**5** is not applied to the second piezoelectric element **14** in the above-described manner, a great meniscus vibration does not easily stop after the ink ejection is complete, and thus a great reduction in the driving frequency is necessary (see FIG. **19**D to FIG. **19**H).

Next, referring to FIGS. **17**A and **17**B and FIGS. **20**A to **20**F, a description is given below as to the behavior of the meniscus **12** of ink in a nozzle that does not eject ink.

In an initial state before the recovery operation is performed, the provision of the liquid-repellent layer **15** formed on the inner wall of the ejection orifice **7** ensures that the meniscus **12** is kept at an inner opening end, at the boundary with the liquid chamber **9**, of the ejection orifice **7** (see FIG. **20**A). Because ink is not ejected, no driving voltage is applied to the first piezoelectric element **11***a* (see FIG. **17**A). The driving unit **21** shown in FIG. **3** outputs the voltage pulse P**5** to the second piezoelectric element **14** synchronously with the applying of the voltage pulse P**5** to the nozzle that is used to eject ink. In response, the meniscus **12** vibrates (see FIG. **20**B to FIG. **20**D).

In the present embodiment, as described above, the same voltage pulse is applied to the second piezoelectric element **14** of the nozzles regardless of the nozzles are used to eject ink whereby the ejection orifices **7** are prevented from being clogged with ink due to an increase in viscosity that occurs when nozzles are not used while suppressing the residual vibration that occurs in nozzles used to eject ink. In the present embodiment, the voltage pulse applied to the second piezoelectric element **14** is equal for all nozzles regardless of whether the nozzles are used to eject ink, and thus it is not necessary to switch the voltage pulse depending on the nozzles, and thus a control process is very simple.

While the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

This application claims the benefit of Japanese Patent Application No. 2011-093013 filed Apr. 19, 2011, which is hereby incorporated by reference herein in its entirety.

What is claimed is:

1. A liquid ejection head comprising:

a plurality of ejection orifices, wherein each ejection orifice is configured to eject liquid through the ejection orifice;

a plurality of liquid chambers, wherein each liquid chamber is configured to communicate liquid individually with a corresponding ejection orifice;

a plurality of piezoelectric actuators, wherein a piezoelectric actuator is disposed individually for a corresponding liquid chamber and configured to generate energy to eject liquid through the corresponding ejection orifice;

a plurality of driving units, wherein a driving unit is configured to individually drive a corresponding piezoelectric actuator; and

a control unit configured to control the plurality of driving units so that a driving unit outputs, to a corresponding piezoelectric actuator, a first voltage pulse or a second voltage pulse, wherein the first voltage pulse drives a corresponding piezoelectric actuator to eject liquid through the corresponding ejection orifice and the second voltage pulse drives a corresponding piezoelectric actuator to vibrate a corresponding meniscus of liquid such that the meniscus vibrates within the corresponding liquid chamber in a state in which the meniscus is held within the liquid chamber and causes the meniscus to protrude out of the ejection orifice without ejecting liquid after the vibrating of the meniscus has stopped,

wherein the control unit selects, from the plurality of ejection orifices, one or more ejection orifices used to eject liquid and controls driving units corresponding to the selected ejection orifices such that these driving units output the first voltage pulse to thereby perform a recording operation, and, concurrently, the control unit controls driving units corresponding to ejection orifices that are not used to eject liquid such that these driving units output the second voltage pulse to thereby perform a recovery operation concurrently with the recording operation.

2. The liquid ejection head according to claim **1**, wherein a liquid-repellent layer is formed on an inner wall of each ejection orifice.

3. The liquid ejection head according to claim **1**, wherein each piezoelectric actuator includes a first piezoelectric actuator, for generating energy to eject liquid through a corresponding ejection orifice, and a second piezoelectric actuator, wherein the second piezoelectric actuator is disposed such that a distance of the second piezoelectric actuator from the corresponding ejection orifice is greater than a distance of the first piezoelectric actuator from the ejection orifice,

wherein the control unit controls driving units assigned to drive the first piezoelectric actuators to eject liquid and perform the recording operation, and the control unit controls driving units assigned to drive the second piezoelectric actuators to output, to the second piezoelectric actuators, a third voltage pulse having a pulse width that is greater than a pulse width of the second voltage pulse such that corresponding meniscuses are held within the liquid chambers corresponding to the second piezoelectric actuators due to expansion of the liquid chambers corresponding to the second piezoelectric actuators caused by voltage pulse.

4. The liquid ejection head according to claim **1**, wherein the second voltage pulse drives a corresponding piezoelectric actuator to vibrate a corresponding meniscus of liquid such that the meniscus vibrates only within the corresponding liquid chamber and not within a corresponding ejection orifice.

5. The liquid ejection head according to claim **1**, wherein a piezoelectric actuator is disposed individually for a corresponding liquid chamber outside the liquid chamber and outside of a flow path of the liquid.

6. A method of driving a liquid ejection head, wherein the liquid ejection head includes a plurality of ejection orifices, wherein each ejection orifice is configured to eject liquid through the ejection orifice, a plurality of liquid chambers, wherein each liquid chamber is configured to communicate liquid individually with a corresponding ejection orifice, a plurality of piezoelectric actuators, wherein a piezoelectric actuator is disposed individually for a corresponding liquid chamber and configured to generate energy to eject liquid through the corresponding ejection orifice, and a plurality of driving units, wherein a driving unit is configured to individually drive a corresponding piezoelectric actuator, the method comprising:

controlling the plurality of driving units so that a driving unit outputs, to a corresponding piezoelectric actuator, a first voltage pulse or a second voltage pulse, wherein the first voltage pulse drives a corresponding piezoelectric actuator to eject liquid through the corresponding ejection orifice and the second voltage pulse drives a corresponding piezoelectric actuator to vibrate a corresponding meniscus of liquid such that the meniscus vibrates within the corresponding liquid chamber in a state in which the meniscus is held within the liquid chamber and causes the meniscus to protrude out of the ejection orifice without ejecting liquid after the vibrating of the meniscus has stopped;

selecting, from the plurality of ejection orifices, one or more ejection orifices used to eject liquid; and

controlling driving units corresponding to the selected ejection orifices such that these driving units output the first voltage pulse to thereby perform a recording operation by ejecting liquid, and, concurrently, controlling driving units corresponding to ejection orifices that are not used to eject liquid such that these driving units output the second voltage pulse to thereby perform a recovery operation concurrently with the recording operation.

7. The method according to claim **6**, wherein controlling driving units to output the second voltage pulse includes applying a voltage pulse to the piezoelectric actuators to draw the corresponding meniscuses into the corresponding liquid chambers, and then applying a voltage pulse to the piezoelectric actuators after the corresponding meniscuses have been drawn into the corresponding liquid chambers to vibrate the meniscuses within the liquid chambers.

8. The method according to claim **6**, wherein each piezoelectric actuator includes a first piezoelectric actuator, for generating energy to eject liquid through a corresponding ejection orifice, and a second piezoelectric actuator, wherein the second piezoelectric actuator is disposed such that a distance of the second piezoelectric actuator from the corresponding ejection orifice is greater than a distance of the first piezoelectric actuator from the ejection orifice,

wherein controlling driving units corresponding to the selected ejection orifices includes controlling driving units assigned to drive the first piezoelectric actuators to eject liquid and perform the recording operation, and wherein controlling driving units corresponding to ejection orifices that are not used to eject liquid includes controlling driving units assigned to drive the second piezoelectric actuators to output, to the second piezoelectric actuators, a third voltage pulse having a pulse width that is greater than a pulse width of the second voltage pulse such that corresponding meniscuses are held within the liquid chambers corresponding to the second piezoelectric actuators due to expansion of the liquid chambers corresponding to the second piezoelectric actuators caused by voltage pulse.

9. A liquid ejection head comprising:

a plurality of ejection orifices, wherein each ejection orifice is configured to eject liquid through the ejection orifice;

a plurality of liquid chambers, wherein each liquid chamber is configured to communicate liquid individually with a corresponding ejection orifice;

a plurality of first piezoelectric actuators, wherein each first piezoelectric actuator is disposed individually for a corresponding liquid chamber and configured to generate energy to eject liquid through the corresponding ejection orifice;

a plurality of second piezoelectric actuators, wherein each second piezoelectric actuator is disposed such that a distance of each second piezoelectric actuator from a corresponding ejection orifice is greater than a distance of a corresponding first piezoelectric actuator from the corresponding ejection orifice;

a plurality of first driving units, wherein each first driving unit is configured to individually drive a corresponding first piezoelectric actuator;

a second driving unit configured to simultaneously drive all second piezoelectric actuators; and

a control unit configured to control the first driving units and the second driving unit, wherein a liquid-repellent layer is formed on an inner wall of each ejection orifice, wherein the control unit selects, from the plurality of ejection orifices, one or more ejection orifices used to eject liquid and controls the first driving units corresponding to the selected ejection orifices such that the first driving units output the first voltage pulse to eject liquid from the selected ejection orifice to thereby perform a recording operation, and the control unit controls the second driving unit to output the second voltage pulse to the second piezoelectric actuators such that a meniscus of liquid in each ejection orifice other than the selected ejection orifices is vibrated in a state in which the meniscus is held within the corresponding liquid chamber and causes the meniscus to protrude out of the ejection orifice without ejecting liquid after the vibrating of the meniscus has stopped to thereby perform a recovery operation.

10. The liquid ejection head according to claim **9**, wherein the second voltage pulse is set such that expanding of the liquid chamber is started in response to the meniscus of liquid of the selected ejection orifice starting moving toward the ejection orifice, and contracting of the liquid chamber is started in response to the meniscus of liquid of the selected ejection orifice starting moving away from the ejection orifice.

11. A liquid ejection head comprising:

ejection orifices, wherein each ejection orifice is configured to eject liquid through the ejection orifice;

liquid chambers, wherein each liquid chamber is configured to communicate liquid individually with a corresponding ejection orifice; and

piezoelectric actuators, wherein each piezoelectric actuator is disposed individually for a corresponding liquid chamber and configured to generate energy to eject liquid through the corresponding ejection orifice, wherein each piezoelectric actuator is first driven to expand a volume of a corresponding liquid chamber to thereby displace a meniscus of liquid from the ejection orifice into the liquid chamber, and thereafter the piezoelectric actuator is driven to vibrate the meniscus in a state in which the meniscus is held within the liquid chamber and causes the meniscus to protrude out of the ejection orifice without ejecting liquid after the vibrating of the meniscus has stopped.

12. A method of driving a liquid ejection head: that includes ejection orifices, wherein each ejection orifice is configured to eject liquid through the ejection orifice, liquid chambers, wherein each liquid chamber is configured to communicate liquid individually with a corresponding ejection orifice, and piezoelectric actuators, wherein each piezoelectric actuator is disposed individually for a corresponding liquid chamber and configured to generate energy to eject liquid through the corresponding ejection orifice, the method comprising:

first driving each piezoelectric actuator to expand a volume of a corresponding liquid chamber to thereby displace a meniscus of liquid from the ejection orifice into the liquid chamber; and

thereafter driving the piezoelectric actuator to vibrate the meniscus in a state in which the meniscus is held within the liquid chamber and causes the meniscus to protrude out of the ejection orifice without ejecting liquid after the vibrating of the meniscus has stopped.

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